Research Article

Changing fertilizer management practices in sugarcane production: Cane grower survey insights

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Abstract: Research focused on understanding wider systemic factors driving behavioral change is limited with a dominant focus on the role of individual farmer and psychosocial factors for farming practice change, including reducing fertilizer application in agriculture. Adopting a wider systems perspective, the current study examines change and the role that supporting services have on fertilizer application rate change. A total of 238 sugarcane growers completed surveys reporting on changes in fertilizer application along with factors that may explain behavior change. Logistic regressions and negative binomial count-data regressions were used to examine whether farmers had changed fertilizer application rates and if they had, how long ago they made the change, and to explore the impact of individual and system factors in influencing change. Approximately one in three sugarcane growers surveyed (37%) had changed the method they used to calculate fertilizer application rates for the cane land they owned/managed at some point. Logistic regression results indicated growers were less likely to change the basis for their fertilizer calculation if they regarded maintaining good relationships with other local growers as being extremely important, they had another source of off-farm income, and if they had not attended a government-funded fertilizer management workshop in the five years preceding the survey. Similar drivers promoted early adoption of fertilizer practice change; namely, regarding family traditions and heritage as being unimportant, having sole decision-making authority on farming activities and having attended up to 5 workshops in the five years prior to completing the survey. Results demonstrated the influence of government-funded services to support practice change.

Keywords: behavior change; fertilizer application; theory; systems science; sugarcane; social norms; extension services; agronomy; management practices.

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1. Introduction

The Great Barrier Reef (GBR) World Heritage Area off the north eastern coast of Queensland, Australia is a global ecological and cultural icon that has been estimated to contribute more than $6 billion annually to Australia's national economy (Deloitte Access Economics 2017). The *2017 Scientific Consensus Statement* concluded that, along with the existential threat posed by climate change, poor water quality is a major factor contributing to the declining condition of the GBR's coastal and reef ecosystems (Waterhouse et al. 2017). Discharges of nutrients, fine sediments, and pesticides have been identified as the greatest water quality-related risks to the Reef (Waterhouse et al. 2017), leading to substantial target reductions in end-of-catchment nutrient and fine sediment loads along the GBR coastline (State of Queensland 2018). Challenging nutrient load reductions (50%-70% from modelled 2012-12 levels) have been set for the Wet Tropics region, where sugarcane is the major agricultural crop (State of Queensland 2018).

Improved fertilizer management practice in cane production is a key component in plans to achieve these ambitious targets (State of Queensland 2019). However, despite trialing a range of different approaches (e.g. agricultural extension advice, industry-led certification programs, federally-funded grants for equipment upgrades, and market-based incentives (Commonwealth of Australia 2014; Sugar Research Australia 2013), it has proved extremely difficult to persuade cane growers to reduce fertilizer application rates (Commonwealth of Australia and Queensland Government 2018).

Research under the Federal Government funded National Environmental Science Program's Tropical Water Quality Hub (NESP TWQ) (https://nesptropical.edu.au) has begun to address this issue by harnessing social marketing approaches to investigate potential reasons for growers' unwillingness to change their fertilizer application rates (Hay, Eagle, and Saleem 2019; Rundle-Thiele 2018). In NESP TWQ-funded research Hay et al. (2019) applied structural equation modelling (after Preacher et al. (2007)) to attitudinal and behavioral data collected in a survey completed by cane growers (Farr et al. 2017). This research identified that individual attitudes and perceived subjective norms help shape growers' fertilizer application choices, in line with Ajzen's Theory of Reasoned Action (Ajzen 1991, 2011). Their work supports previous studies such as Zeweld et al. (2017) who applied the Theory of Planned Behavior (hereafter referred to as TPB), which is an extension of the Theory of Reasoned Action, as a theoretical framework to analyze intentions to change growing practices. The Zeweld et al. (2017) study identified that attitudes and normative issues positively explain farmers' intentions to adopt new growing practices and perceived behavioral control influences intention to apply minimum tillage.

Psychosocial theories such as the TPB suggest that changing the way a farmer thinks (attitudes), their understanding of what other farmers do (social norms) or their ability to perform the recommended behavior (behavioral control) can increase intentions to perform the behavior and this is turn leads to changes in farming practices. However, farming practice change is situated within complex settings. Systems thinking is a conceptual and methodological approach that seeks to address complex problems within the very complexity that produces them (Truong, Saunders, and Dong 2019). It is argued that by modelling the many and varying stakeholders, stakeholder interactions, and including the socio-cultural beliefs and values operating in a system, it is possible to design more effective behavior change initiatives given individual and structural social relationships are taken into account (Brychkov & Domegan, 2017; Domegan et al., 2016). Application of a systems thinking approach acknowledges that behaviors must be addressed within the very complexity that produces them and therefore examining the importance of servicing debt, farm decision making responsibilities, farm size, participation in workshops delivered by extension service and agronomy service providers, grants received, and receipt of off-farm income are examples of factors that can be included to extend understanding of the factors influencing behavior change in order to learn more about how and why practice change occurs. By exploring elements of complexity, including assumptions, socio-cultural beliefs and values, operations and interactions within a system, it is possible to identify factors facilitating and preventing changes in farming practices and water quality improvements to benefit the Great Barrier Reef (GBR).

This study draws on data from the first round of Farr et al's questionnaire survey (Farr et al. 2017), we use count data regression analysis to explore whether concepts from the TPB and wider systems factors can also help explain (self-reported) *early adoption of* lowered fertilizer application behaviors that benefit local waterways through decreased nutrient loads, among sugarcane growers in Queensland's Wet Tropics.

2. Materials and Methods

This paper utilizes secondary data drawn from Farr et al's 2017 face-to-face survey conducted with sugarcane growers in the Wet Tropics (n=238). The survey provided data on attitudes, social norms and perceived behavioral control from a TPB perspective, together with characteristics of growers' farm businesses, participation in a range of practice change initiatives and other individual and socio-demographic characteristics. The survey ascertained the method growers used to calculate the amount of fertilizer they applied on land they owned/managed, and whether they had always used their current method (and if not, how long ago they switched to their current method). The survey also obtained data on the importance growers assigned to key issues when making decisions about what to do on their land. These importance responses were recorded on a seven-point unipolar semantic scale, where a '1' is 'Extremely unimportant or irrelevant', a '4' is 'Neutral' and '7' is 'Extremely important or essential'. Responses regarding the importance growers assigned to three of the issues when making farming decisions: minimizing sediment runoff and/or nutrient losses; safeguarding local waterways; safeguarding the GBR, can be collectively regarded as a TPB measure of environmental attitude (Cronbach's α=0.86). The importance assigned to maintaining family traditions and heritage, maintaining good relations with other local growers, and having efforts recognized by the wider community could be regarded as TPB subjective norms; however Cronbach's α was insufficient to justify combining these three measures into a single indicator (α=0.49), so each item was retained separately. Assigning high importance to servicing debt could be regarded as a TPB perceived behavioral control on intention (particularly as some forms of low-nitrogen fertilizer management require purchase of new equipment) (van Grieken et al. 2010).

Moving beyond TPB constructs, the following farm characteristics were also recorded: decision making responsibilities, farm size an whether or not the farming business obtained income from off-farm activities. Additionally, years of cane growing experience and a self-stated life satisfaction score were recorded as grower characteristics, together with standard socio-demographics. Level of life satisfaction was stated on a scoring scale from 0 to 100, with 100 representing very satisfied, 0 very unsatisfied and 50 neutral. To explore the potential influence of government-funded grants and workshops on change of fertilizer practice, respondents stated how many workshops they had attended (none, five or less, more than five), and how many grants they had applied for (none, three or less, more than three) in the five years preceding the survey. Survey respondents were asked if they were solely responsible for decision making on their property, or whether decision making responsibility was shared with others (spouse, parents, children, brother, in-laws, or others).

A logistic regression model was used to initially identify TPB factors that exerted statistically significant influences on the probability that growers had changed fertilizer practice (i.e. fertilizer application rate) on land they owned/managed. Subsequently, the same logistic regression model was expanded to also include characteristics of the farm business, socio-demographics of respondents, workshop attendance and grants applied as additional drivers of fertilizer practice change. The general statement of the logistic regression model is

$$F_i = f(\boldsymbol{TPB}_i, \boldsymbol{FBC}_i, \boldsymbol{SOC}_i, W_i, G_i) + e_i \quad (1)$$

where F_i is the (binary) response to whether respondent i had changed their fertilizer calculation method (i.e. *fert_practice_change*). $\boldsymbol{TPB}_i$ is a vector of TPB constructs pertaining to grower i's environmental attitudes (*environmental_attitude*), social norms (*family_traditions*, *relationships_local_growers*, *efforts_recognized*) and perceived behavioral controls (*debt_servicing*, *shared_decision*) as described previously. $\boldsymbol{FBC}_i$ and $\boldsymbol{SOC}_i$ are vectors of respondent i's farm business characteristics (*farm_size*, *off_farm_income*) and socio-demographics (*age*, *male*, *cane_growing_experience*, *life_satisfaction*), respectively. W_i and G_i represent the number of

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workshops attended and grants applied for, respectively, in the five years prior to completing the survey. e_i is the error term, which is assumed to follow a binomial distribution.

For those growers who had changed their fertilizer application rate, the number of years since they made that change is also of interest. Specifically, the data can be used to identify factors that influence early adoption of lower water quality risk fertilizer application behaviors among cane growers in the Wet Tropics. The objective here is to analyze in a regression context, the number of years since switching (i.e. *years_switched*), in response, initially, to a set of TPB constructs only as drivers initially, and, subsequently, to TPB constructs, farm business characteristics and grower socio-demographics as additional drivers. The most commonly used count data models in applied studies are the Poisson and negative binomial regression models (Folkersen, Fleming, and Hasan 2018). A Poisson regression model assumes equality of the conditional mean and variance (i.e. equidispersion) of the count variable *years-switched*. If this assumption does not hold (i.e. data exhibit overdispersion whereby the conditional variance exceeds the conditional mean), a negative binomial regression model is more appropriate (Kragt, Roebeling, and Ruijs 2009; Folkersen, Fleming, and Hasan 2018). The negative binomial model for the number of years since grower i switched or changed the basis of their fertilizer practice, y_i, can be written in log-linear form as:

$$\ln y_i = \sigma + \boldsymbol{\beta TPB}_i + \boldsymbol{\gamma FBC}_i + \boldsymbol{\rho SOC}_i + \omega W_i + gG_i + \epsilon_i \quad (2)$$

where the subscript i is an index for respondent; σ is a constant term; $\boldsymbol{\beta}, \boldsymbol{\gamma}$ and $\boldsymbol{\rho}$ are vectors containing the coefficients to be estimated for the vectors of drivers $\boldsymbol{TPB}$, $\boldsymbol{FBC}$ and $\boldsymbol{SOC}$ as defined for Equation (1). The coefficients ω and g are estimated for the independent variables W_i and G_i. ϵ_i is the error term, which is assumed to follow a gamma distribution.

3. Results

3.1. Descriptive statistics

A total of 238 sugarcane growers completed surveys reporting on changes in fertilizer application and focal factors that may explain behavior change. As shown in Table 1, of the 238 Wet Tropics sugarcane growers surveyed, 89 (37%) had at some point changed the method they used to calculate fertilizer application rate for the cane land they owned/managed. Those who had changed their basis for this calculation made that change between 1 and 45 years ago (mean number of years since making the change is 8.4 years and standard deviation is 8.1 years). Descriptive statistics of key data are summarized in Table 1.

Table 1. Descriptive statistics of variables included in the logistic and count data regression models. The number of responses for each variable reflects the number complete answers received.

Variable	Description	Mean	Std. dev.	No. of responses
Dependent variables				
fert_practice_change	Binary variable indicating respondent has changed fertilizer practice (= 1, 0 otherwise)	0.37	0.48	238
years_since_prac_change	Number of number of years since growers changed fertiliser practice	8.38	8.11	84
Independent variables: Theory of planned behavior constructs (**TPB**)				
environmental_attitude[1]	Measure of attitude: minimizing runoff and safeguarding water quality	6.44	0.73	235
family_traditions[2]	Measure of importance of maintaining family traditions and heritage	2.74	0.53	236
relationships_local_growers[1]	Measure of a social norm: maintaining good relationships with other local growers	6.13	0.88	236
efforts_recognized[2]	Measure of a social norm: having efforts recognized by the wider community	2.36	0.78	233
debt_servicing[2]	Perceived behavioral control on intention: prioritizing servicing debt	2.79	0.52	229
Independent variables: Farm business characteristics (**FBC**)				
shared_decision	Perceived behavioral control: in relation to decision making (own decision = 1, joint or shared decision with spouse, parents, children, brother, in-laws, or others = 2)	1.475	0.500	236
farm_size	Size of sugarcane area in hectares	313	596	238
off_farm_income	Binary variable indicating respondent (and/or spouse) has another source of income (=1, 0 otherwise)	0.57	0.50	238
Independent variables: Socio-demographics (**SOC**)				

Variable	Description	Mean	Std. dev.	No. of responses
age	Respondent's age (years)	56.81	12.02	237
male	Binary variable indicating respondent is male (=1, 0 otherwise)	0.97	0.16	234
cane_growing_experience	Number of years respondent has been managing a sugarcane farm	29.34	17.13	231
life_satisfaction	Self-stated level of life satisfaction on a scale between 0 (very unsatisfied), 50 (neutral), and 100 (very satisfied)	78.52	16.58	234
Independent variables: Engagement with workshops and grants (**W** and **G**)				
workshops_attended	Categorical variable indicating the number of workshops attended in the preceding five years (participated in more than 5 =1, participated in 5 or less = 2, not participated in any = 3)	2.0	0.42	236
grants_applied	Categorical variable indicating the number of grants applied for in the preceding five years (applied for more than 3 = 1, applied for 3 or less = 2, did not apply any = 3)	2.13	0.55	235

[1] On a 7-point scale ranging between 1 (Extremely unimportant/irrelevant), 4 (Neutral), and 7 (Extremely important/essential). [2] On a 3-point scale ranging between 1 (Unimportant/irrelevant), 2 (Neutral), and 3 (Important/essential).

3.2. Results of the logistic regressions

Results obtained from fitting a logistic model in linear form to the complete dataset for Model 1 (TBC constructs only) (n = 223) and Model 2 (n = 212) (TPB constructs, FBC, SOC, W & G), with fertilizer practice change as the dependent variable are shown in Table 2. Across both models, relationships with other local growers as a TPB measure of a social norm is a statistically significant driver of fertilizer practice change, all else equal. All other things equal, growers who do *not* regard maintaining good relationships with other local growers as *extremely important* (the baseline category) are more likely to have changed their fertilizer practice. When only including TPB constructs as drivers (Model 1), growers were more like to have changed the basis for their fertilizer calculation rate if they were neutral (as opposed to agreeing or disagreeing) regarding the importance of having their efforts recognized by the wider community as an important factor in their farm decision making, all else equal.

When farm business characteristics, grower socio-demographics and engagement with workshops and grants were added as independent variables, alongside the TPB constructs (Model 2), the TPB construct regarding the importance of maintaining good relationships with other local growers remained significant. Attendance at workshops and having a source of off-farm income were also statistically significant at 10% or better in Model 2. All other things equal, growers whose business has a source of off-farm income are less likely to have changed their fertilizer practice, as are growers who had not attended a fertilizer management workshop in the five years preceding the survey.

The robustness of the logistic regression results in Table 2 is evaluated by the Hosmer-Lemeshow specification test (Cameron and Trivedi 2009) and the area under the ROC curve (Hosmer and Lemeshow 2000). The Hosmer-Lemeshow goodness of fit assessment compares the sample frequency of the *fert_practice_change* variable, within a chosen number of subgroups, with the average predicted probability for each subgroup from the fitted model – under the null hypothesis that the two frequencies are equal i.e. the model is correctly specified (Cameron and Trivedi 2009). Results of Hosmer-Lemeshow's goodness of fit test for Model 1 and Model 2 for 4 through to 9 subgroups suggest that there is no evidence of lack of fit (p-values range from 0.47 (4 groups) to 0.90 (8 groups) for Model 1; p-values range from 0.48 (4 groups) to 0.93 (9 groups) for Model 2). Results based on Model 1 and Model 2 in Table 2 are also evaluated using the area under the ROC (Receiver Operating Characteristics) curve. The areas under the ROC curves for Model 1 and Model 2 are 0.68 and 0.72, respectively, indicating that the predictive ability of Model 2 exceeds the 'acceptable discrimination' ROC threshold of 0.7 as determined by Hosmer and Lemeshow (2000). Furthermore, comparing observed data on *fert_practice_change* against predictions from Model 1 and Model 2, under the assumption of a symmetric threshold (Cameron and Trivedi 2009), shows that the models correctly classified 65.02% and 66.51% of outcomes, respectively.

Table 2. Logistic regression results for Model 1 (only TPB constructs included as independent variables) and Model 2 (all independent variables included).

Dependent variable: *fert_practice_change*

	Model 1		Model 2	
Variable	**Coefficient**	**SE**	**Coefficient**	**SE**
constant	-3.977	2.139	-2.693	2.470
environmental_attitude	0.249	0.265	0.304	0.323
family_traditions[1]				
neutral	0.740	0.872	0.644	0.970
important	0.212	0.829	0.499	0.947
efforts_recognized[1]				
neutral	-0.818*	0.440	-0.746	0.456
important	0.044	0.381	0.188	0.390
debt_servicing[1]				
neutral	1.039	0.941	0.678	0.926
important	1.342	0.839	0.940	0.835
relationships_local_growers[2]				
neutral	1.784**	0.906	2.469**	1.121
important	0.921**	0.471	1.001*	0.530
very important	1.174***	0.340	1.085***	0.366
shared_decision	-0.119	0.301	-0.164	0.333
off_farm_income			-0.579*	0.326
farm_size			0.00032	0.00031
life_satisfaction			0.00059	0.00911
cane_growing_experience			-0.00690	0.00961

	Model 1		Model 2	
Variable	Coefficient	SE	Coefficient	SE
workshops_attended[3]				
participated in 5 or less			-0.326	0.555
not participated in any			-1.818*	1.034
grants_applied[4]				
applied for 3 or less			-0.771	0.519
did not apply any			-0.659	0.640
Number of observations	223		212	
Area under ROC curve	0.680		0.721	
McFadden's R^2	0.077		0.121	
Count R^2	0.650		0.665	

Note: Regression with robust standard errors. ***, **, * are significant at the 1%, 5% and 10% levels, respectively. [1] Baseline category is *not important*. [2] Baseline category is *extremely important*. [3] Baseline category is *participated in more than 5*. [4] Baseline category is *applied for more than 3*.

3.2. Results of the negative binomial regressions

The Poisson regression model was first implemented to estimate the mean number of years since grower i changed fertilizer practice, conditional on grower i's TPB constructs ($\boldsymbol{TPB}$) farm business characteristics ($\boldsymbol{FBC}$), socio-demographics ($\boldsymbol{SOC}$), attendance at workshops and grant applications (W and G). Comparison of the mean number of years since growers changed fertilizer practice (8.38) with the variance (65.77) suggests overdispersion. Following Cameron and Trivedi (2009), a test of overdispersion on the Poisson regression results for Model 1 rejects (p = 0.006) the null hypothesis of equidispersion, $(i.e. Var(y|\boldsymbol{TPB}) = E(y|\boldsymbol{TPB}))$, indicating the presence of significant overdispersion. Repeating the same overdispersion test on Poisson regression results for Model 2 produces the same outcome (p = 0.001). The negative binomial estimates of the overdispersion parameter, α, are 0.378 for Model 1 and 0.218 for Model 2. The likelihood ratio test of H_0: $\alpha = 0$ (i.e. no overdispersion) is rejected for both Model 1 and Model 2. Based on the outcomes of these overdispersion tests, a negative binomial specification of *years_since_prac_change* is used in subsequent analyses.

Table 3 shows the estimation results for negative binomial Model 1 and Model 2. For Model 1 (TPB constructs only), all else equal, regarding it as being unimportant to maintain family traditions and heritage when making decisions about managing the farm acts to *advance* the decision to change fertilizer practice. Conversely, being neutral regarding the importance of servicing debt as a factor in farm decision making acts to *delay* fertilizer practice change. Model 1 also reveals that two further factors also influence the timing of practice change. Regarding it as being *extremely important* to maintain good relationships with other local growers' acts to *advance* the decision to change fertilizer practice, whereas agreeing that safeguarding the environment from adverse impacts of fertilizer runoff is an important factor in farm decision making acts to *delay* the adoption decision. When farm business characteristics, grower socio-demographics and engagement in workshops and grants are added as drivers (Model 2), the following statistically significant factors persist: being inclined to maintain family traditions and heritage; being neutral regarding the importance of servicing debt; and regarding it as being extremely important to maintain good relationships with other local growers. However, the influence of environmental attitude on delaying the decision to change fertilizer practice becomes insignificant. Under Model 2, all else equal, growers with more years of experience and those who attended up to five workshops in the preceding five years were more likely to be early adopters of fertilizer practice change. The positive link between early adoption of practice change and years of experience growing sugarcane may simply reflect the increased length

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of time these growers have been in the industry. Finally, having multiple decision makers (joint or shared decision with spouse, parents, children, brother, in-laws, or others) in farm management activities acts to delay the decision to change the basis of fertilizer rate calculations.

Table 3. Negative binomial regression results for Model 1 (TPB construct included as independent variables) and Model 2 (all independent variables are included).

Dependent variable: *years_since_prac_change*

	Model 1		Model 2	
Variable	**Coefficient**	**SE**	**Coefficient**	**SE**
constant	6.838	1.166	5.460	1.151
environmental_attitude	-0.411**	0.192	-0.273	0.200
family_traditions[1]				
neutral	-1.126***	0.366	-1.035***	0.258
important	-0.946***	0.340	-1.142***	0.191
efforts_recognized[1]				
neutral	-0.254	0.265	-0.170	0.217
important	0.060	0.183	0.088	0.146
debt_servicing[1]				
neutral	-0.822**	0.411	-0.903*	0.493
important	-0.218	0.381	-0.597	0.502
relationships_local_growers[2]				
neutral	-0.143	0.425	0.241	0.322
important	-0.583*	0.313	-0.335	0.243
very important	-0.747***	0.265	-0.445**	0.209
shared_decision	-0.283	0.188	-0.301*	0.167
off_farm_income			-0.264	0.175
farm_size			0.00006	0.00007
life_satisfaction			-0.00235	0.00557
cane_growing_experience			0.0208***	0.0049
workshops_attended[3]				
participated in 5 or less			0.403**	0.162
not participated in any			0.491	0.394
grants_applied[4]				
applied for 3 or less			0.020	0.213
did not apply any			-0.018	0.282
Number of observations	82		81	
Log likelihood	-240.374		-223.400	
AIC	6.277		6.183	

Note: Regression with robust standard errors. ***, **, * are significant at the 1%, 5% and 10% levels, respectively. [1] Baseline category is *not important*. [2] Baseline category is *extremely important*. [3] Baseline category is *participated in more than 5*. [4] Baseline category is *applied for more than 3*.

4. Discussion

The need to systematically compare and contrast theoretical perspectives to advance understanding has been identified (Rundle-Thiele et al., 2019). By understanding which theory offers the greatest predictive capability researchers can deliver guides for practice while simultaneously building the evidence base to advance knowledge. Within farming management practice change research a strong reliance on theoretical perspectives that focus attention on individuals is evident. Researchers have applied psychosocialmodels such as Transtheoretical Model of Change (Lemken, et al., 2017), Health Belief Model (Abdollahzadeh et al., 2018) and the Theory of Planned Behaviour (Márquez-Garciá et al., 2018; Zeweld, et al. 2017). These studies have focused attention on understanding farmer beliefs, farmer's readiness to change, knowledge, barriers to adoption, farmer goals, benefits of practice change adoption, self-efficacy, perceived usefulness, perceived ease of operation and normative beliefs. Psychosocial theories have assisted researchers to identify how farmers think.

Previous studies applying Ajzen's Theory of Reasoned Action (Ajzen 1991, 2011) and the subsequent Theory of Planned Behaviour (TPB) have identified that individual attitudes and perceived subjective norms can help shape change in growers management practices. For example, Zeweld et al. (2017) applied the Theory of Planned Behavior as the theoretical framework to analyze intentions to change growing practices. The Zeweld et al. (2017) study identified that attitudes and normative issues positively explain farmers' intentions to adopt new growing practices and perceived behavioral control influences intention to apply minimum tillage. This finding was corroborated in Hay et al. (2019) who applied structural equation modelling to attitudinal and behavioral data identifying that individual attitudes and perceived subjective norms help shape sugarcane growers' fertilizer application choices. These approaches indicate the important role of social norms. By adopting a dynamic analytical approach that examines why farmers do and don't change, the role of social norms can be further illuminated. The current study identified that 37% of farmers reported changing their fertilizer rates and early adopters of practice change were less concerned with what other farmers thought, which demonstrates that social norms may be more relevant to adoption across the wider farmer community but are less of a consideration for early adopters of practice change. Further research will be needed to confirm (or deny) this study finding.

Dominant use of psychosocial theories demonstrates that researchers have come to understand farming practice change as a process where an understanding of the way that farmers think and feel is required to drive behavioural change (Rothman, 2009). While psychosocial theories do serve a purpose (i.e. they provide an understanding of individual level factors that can be related to explaining current behavior and predicting behavioral change), investigators cannot 'habituate to the perspective afforded by psychosocial theory in the way that one can forget that one is wearing glasses' (Rothman, 2009, p. 150s). The dominant psychosocial theoretical focus restricts understanding, and therefore monitoring and measurement practices, to individuals whose behavior needs to change, and in so doing, ignores the fact that farming practice change occurs in partnerships among stakeholders. Systems standpoints that consider practice change within a constellation of actors, actions and interactions, or within a complex stakeholder system where mutual value is realized between partners, can extend understanding of how farming practice change can be facilitated and enabled (see McHugh, Domegan, & Duane, 2018).

Examination of the farming practice change evidence base indicates that alternative theoretical viewpoints do exist. For example, the Diffusion of Innovation approach (Blythe et al. 2017; Goldberger et al., 2015) captures a range of social factors including access to extension support services, the role of opinion leaders, financial costs and market forces. Socio-ecological frameworks organize understanding into individual, social and institutional setting and regulation levels considering additional factors such as network relations. Application of systems frameworks such as Agricultural Innovation Systems (AIS) (see Borremans et al. 2018) focus attention on structural elements (e.g., actors/roles); functions in an innovation system (e.g., process dynamics); and analyses of how elements and functions interact to identify relative conditions or processes necessary for innovation. In line with wider socio-ecological or systems frameworks the present study extended research focus beyond individual factors to consider the role partners may play in shaping practice change. The results of this study indicate that farmers who had attended workshops in the last five years were more likely to have changed their fertilizer application rates. This study demonstrates how surveys can be used to extend research focus to capture the role of actors within the practice change system.

This study is limited to available data within a survey that had previously been applied to examine sugarcane farming practice change in one Australian region. The limitations of this study provide opportunities for future research including extending research focus to other regions and agribusiness sectors using available survey data to examine factors contributing to (or acting against) practice change. Further primary research is recommended to extend understanding of additional systems factors supporting or denying practice change. Factors including experience with support services, satisfaction and willingness to recommend service providers, and other social and systems factors as indicated in AIS and Diffusion of Innovation approaches should be examined across regions and agri-business contexts to build a Theory of Farming Practice Change ensuring the actions of stakeholders and interactions between actors are monitored and measured.

5. Conclusions

Changing fertilizer application rates is a complex problem. By approaching the problem through a wider systems lens and examining the role that other actors have in shaping farming management practice change (e.g. agronomy and extension service providers who support practice change through one-to-one consultations and groups workshops and governments who provide funding through grant schemes) an understanding of how and why farmers change fertilizer application and other farming practices emerges. This study demonstrates how available survey data can be examined to identify rates of farming management practice change and the wider systems factors contributing to reported changes. This study challenges researchers to extend understanding beyond current dominant psychosocial individual based research enquiries. In this study, social norms were an influencing factor and farmers who do not consider it essential to maintain good relationships with other local growers were more likely to report changes in fertilizer application rates. The importance of initiatives supporting practice change (e.g. grants and workshops) were highlighted in this study. Growers who had attended workshops in the last five years reported lowering fertilizer application rates and workshop attendance assisted in promoting earlier adoption of this behavior change. By understanding more about the constellation of actors and actions that occur within the farming context a wider understanding of factors contributing to farming practice change can emerge.

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